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TANDEM DRY GAS SEALS – Design and Maintenance Considerations for enhanced reliability and performance

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Girish Kamal is currently working as Principal Rotating Equipment Engineer with the Centre of Excellence Division of PETRONAS Carigali Sdn. Bhd. in Kuala Lumpur. He has more than 28 years of extensive and diversified experience in the Oil and Gas Industry in the fields of rotating equipment management for onshore and offshore applications including specifications, design approvals, witness testing, inspection, commissioning, installation, maintenance and technical services. Prior to joining PETRONAS Carigali, he worked with Dolphin Energy Gas Plant in Qatar as Head of Machinery Reliability, with PETRONAS Carigali in Peninsular Malaysia Office as Unit Head for the Condition Based Maintenance department, with Engineers India Limited as Deputy Manager (Rotating Equipment) and also with Oil and Natural Gas Corporation Limited in India as Executive Mechanical Engineer. He holds a BE degree in Mechanical Engineering and an MBA qualification. He is also a Certified Reliability Professional.

ABSTRACT

Dry Gas Seals have been in existence in the process centrifugal compressor industry for the last three decades and majority of the compressor units in operation today are installed with Dry Gas Seals. DGS sealing and the associated systems gained importance predominantly due to unreliability, high operating and maintenance costs and hazardous characteristics inherent with the conventional lubricated shaft sealing systems.

This Technical Brief shall cover the best practices to improve dry gas seals reliability and performance including:

- Design and Maintenance considerations
- Major factors affecting Dry Gas seals life and efficient operation
- Seal Gas supply and control requirements
- Primary Gas seal venting and health monitoring
- Secondary Gas seal venting and health monitoring
- Separation gas supply and control requirements
- Recommended Alarm and Shutdown conditions

INTRODUCTION

Dry gas seals are gas-lubricated, mechanical, non-contacting, end-face seals, consisting of a *mating ring* and a *primary ring*. Figure 1 shows the principal components of a Tandem Dry Gas Seal configuration as listed below:

- A mating rotating ring.
- A primary stationary ring.
- Inboard process side labyrinth seal separating the process gas from gas seal.
- Outboard barrier seal separating the gas seal from compressor bearings.

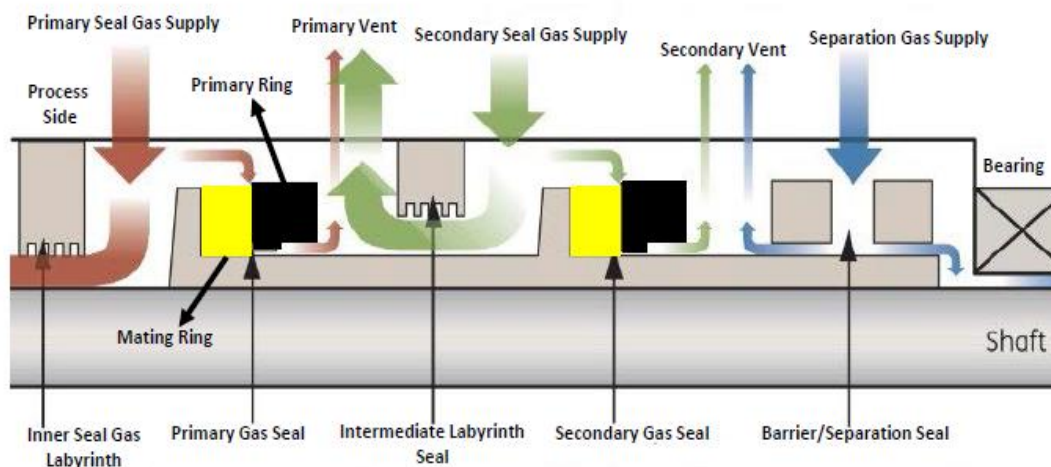


Figure 1 Principal Components of a Tandem Dry Gas Seal

There is always a Thin Gas Film between rotating and stationary faces and Groove Pattern in the mating ring generates the dynamic force to provide lift. During compressor operation, the entire pressure drop is absorbed by the Primary seal while, the Secondary Seal act as a backup to the Primary Seal upon its failure. Refer to Figure 2 [API 614, 2014].

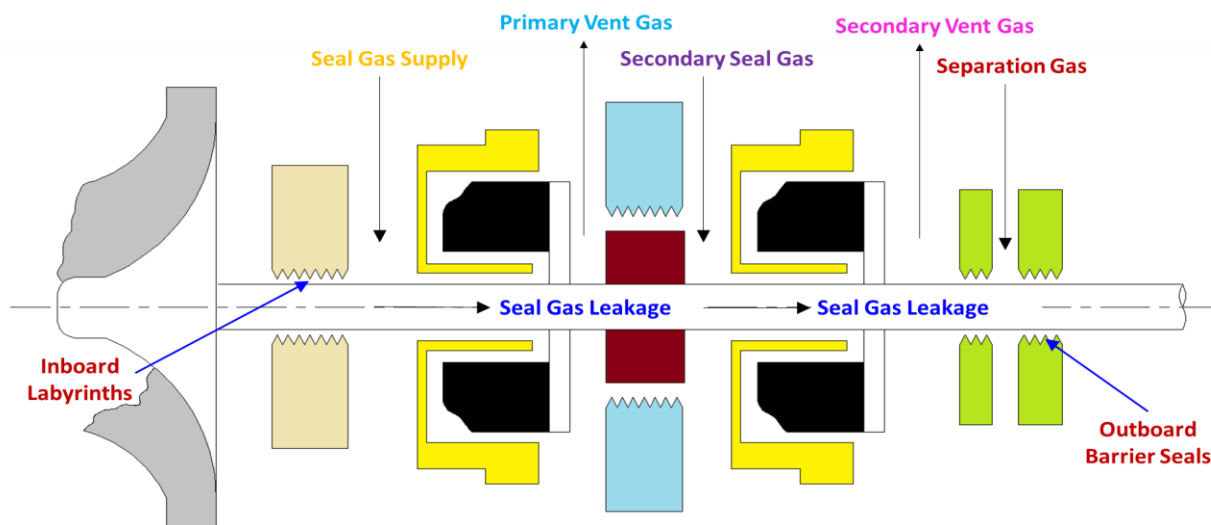


Figure 2 Tandem DGS with intermediate labyrinth seal

Separation Seal (Barrier Seal)

Separation seal is usually a labyrinth type seal installed on the outboard end of the dry gas seal that separates the gas seal from the compressor bearings. It is a common practice to use nitrogen or air as separation gas for the separation seals. But due to high nitrogen consumption experienced with labyrinth type separation seals, another viable option would be to use non-shaft contacting carbon segmented ring, since their nitrogen consumption requirements are comparatively much lower. On the other hand, carbon segmented ring type have higher manufacturing cost. In addition, when non-shaft contacting carbon ring separation seal is used, required dew point of supplied nitrogen need to be carefully taken into consideration.



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MAJOR FACTORS AFFECTING DRY GAS SEALS LIFE AND EFFICIENT OPERATON

There are four important factors leading to the degradation and reduced reliability of Dry Gas Seal (DGS) life and efficient operation:

- Dirty and un-cleaned process gas coming in contact with the seal mating faces (Figure 3);
- Poor seal gas supply quality due to inadequate system design including inadequate filtration (Figure 4);
- Migration of bearing lubrication oil in to seal envelope resulting in contamination; and
- Hydrate and liquid formation (condensate) on seal faces due to Joule Thomson (JT) cooling effect while seal gas expanding and loss of dew point margin.



Figure 3 Dirty process gas coming in contact with DGS



Figure 4 Poor seal gas supply quality – inadequate filtration

Dry Gas Contamination:

- Loss of Seal gas DP across the process labyrinth results in unfiltered and dirty process gas migration from compressor to primary seal face thus resulting in damage.
- Inadequate source pressure during start-up and settle out condition leads to contamination at seal faces.
- Liquid carry over from the process or condensate due to seal gas supply temperature loss below the dew point causing heavy contamination (Figure 5).
- Inadequate filtration of the seal supply gas - main contributor to the poor seal gas supply quality.
- Loss of barrier gas pressure results in lube oil migration from bearing housing into seal envelope or due to improper functioning of the barrier seals as required (Figure 6).

Contaminated with oil like liquid and black dusty substance. Contact traces on the balance diameter.

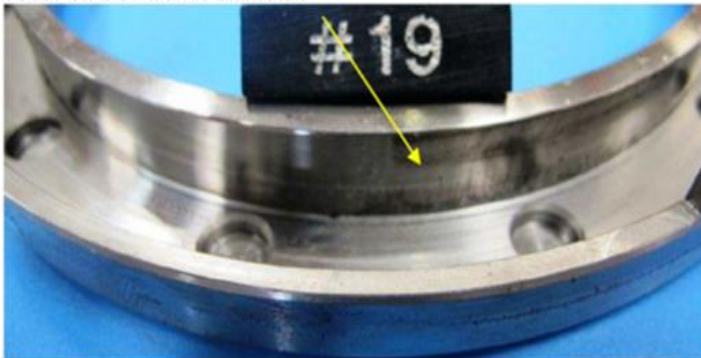


Figure 5 Liquid carry-over due to inadequate dew point margin

Contaminated with oil like liquid. Heavy Contact traces on the sealing surface

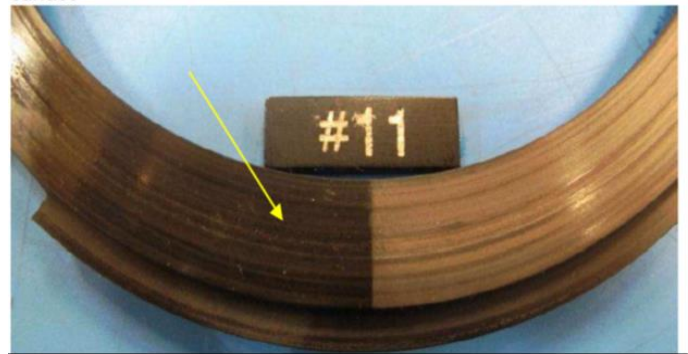


Figure 6 Lube oil migration to seal envelope



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SEAL GAS SUPPLY AND CONTROL REQUIREMENTS

Seal Gas Supply – Clean and Dry

- As shown in Figure 7 [API 614, 2014], Seal gas is injected between the process side labyrinth seal and Primary gas seal (inboard seal). Majority of injected seal gas passes across the process side labyrinth seal into the compressor (process side).
- Seal gas supply need to be sourced at sufficient pressure to cover the entire compressor operating range including transient conditions such as startup, shutdown, idle, and all steady-state conditions.
- It is recommended to install seal gas boosters to ensure supply of seal gas during standstill and transient conditions, if a reliable source of seal gas with suitable conditions is not available for these transient times (particularly during the startup).
- Recommended Seal gas source supply pressure > 50 psi above the required sealing pressure.
- Provision of pressure gauge upstream of the filter module assembly for indicating the seal gas supply pressure.
- Seal gas supply quality recommended at system inlet at connection point:
 - Solid particle size ~ 10 um or smaller
 - At least 99.97% liquid free
- Hydrate and Liquid formation (condensate) on seal faces due to Joule Thomson (JT) cooling effect can be prevented by keeping a margin of 20 deg C above the seal gas dew point throughout the entire seal gas system.
- A detailed seal gas dew point analysis is required to validate the suitability of the process gas while configuring seal gas system. Liquid carry over from the process or condensate can be prevented by adding liquid knock-out systems.
- In addition, Computer simulation is also needed to determine the level of superheating needed to meet the criterion of 20 deg C dew point margin. Accordingly, seal gas heaters can be introduced for super heating the gas, if needed. Heat tracing (plus insulation) of seal gas supply line is also recommended if ambient temperature falls below the seal gas dew point.

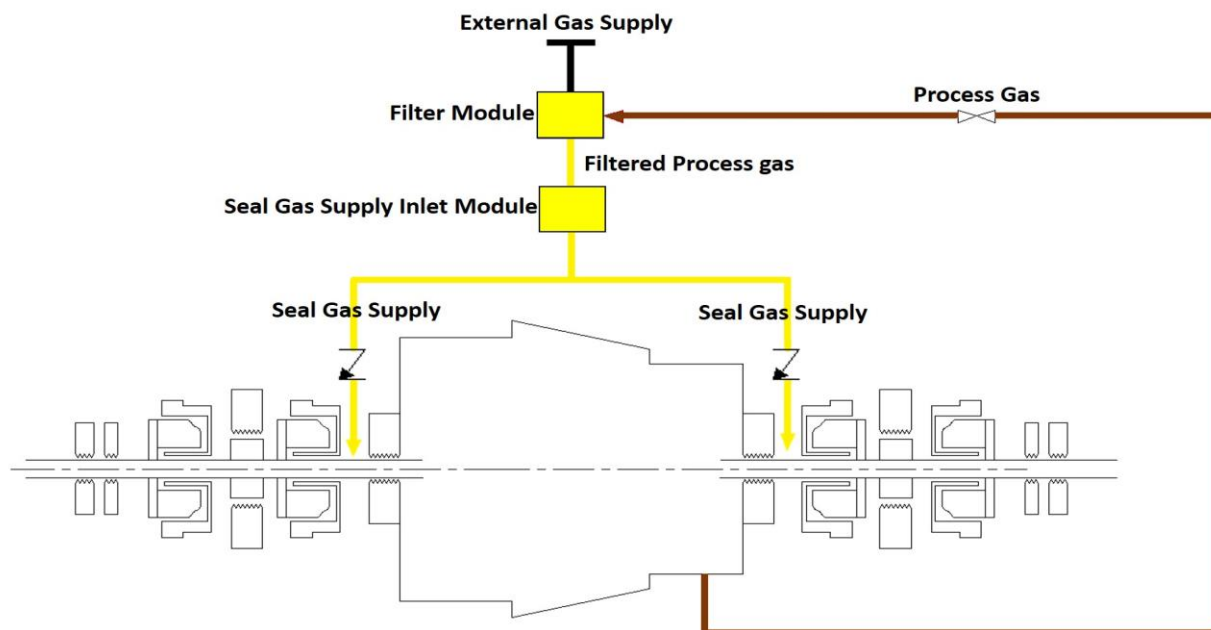


Figure 7 Dry and Filtered Seal Gas supply

Filtered Clean and Dry Gas – a must

- Duplex filter assemblies with change-over valve to allow filter element replacement during operation.
- Filtration to be at least 3 um (absolute) or better.
- Differential pressure gauge/transmitter (PDT) with high differential pressure alarm.
- Coalescing filters for wet gas with automatic/manual drainage.



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Seal Gas Supply Controls

The main objective of an effective and efficient seal gas supply control system is to ensure that the sealing gas is injected between the process side labyrinth seal and the dry gas seal at sufficient pressure to prevent any migration of dirty unfiltered process gas across the inner process labyrinth into the dry gas seal.

Two methods of controlling and regulating the seal gas supply to Dry Gas Seals are employed:

- Differential Pressure Control
- Flow Control

Differential Pressure Control

- Use of Differential Pressure (DP) control valve to control seal gas supply pressure as shown in Figure 8 [John S Stahley, 2002 – Turbomachinery Symposium]
- Typically regulating the pressure to 5 ~ 10 psi above the seal gas reference pressure is normally considered
- DP control would result in high seal gas flows through the inner Process side labyrinths
- With DP control, high variations in seal gas flows could result from variations in inner seal labyrinth clearances

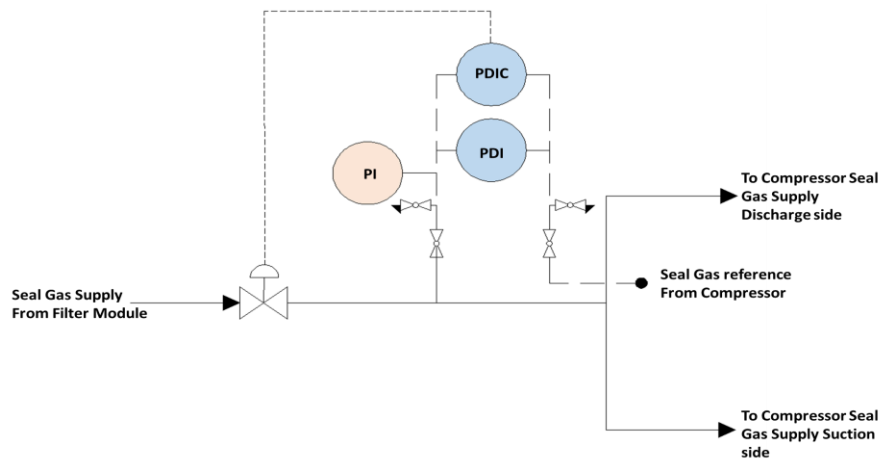


Figure 8 Differential Pressure Control

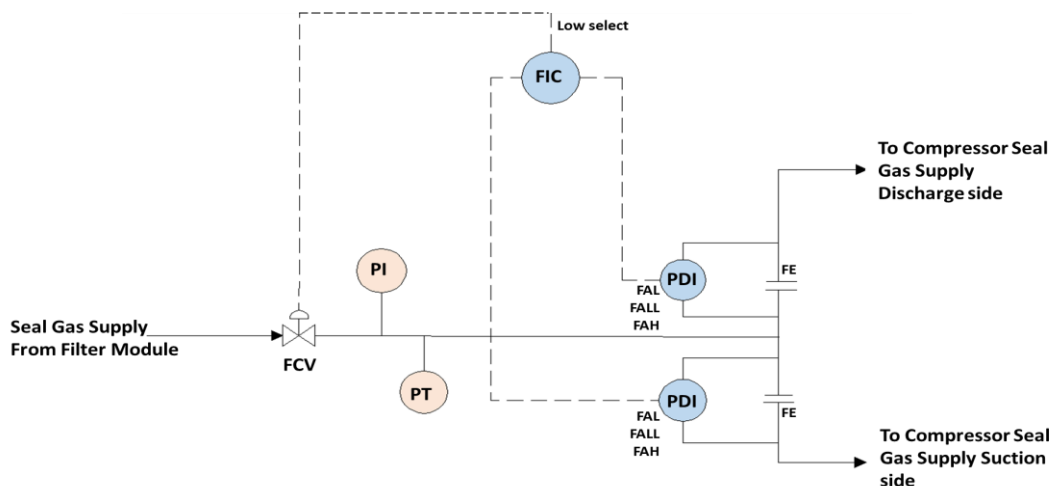


Figure 9 Flow Control



Flow Control

- Seal gas flow is regulated using Flow Control to control the seal gas supply as shown in Figure 9 [John S Stahley, 2002 – Turbomachinery Symposium].
- Use of a restriction orifice upstream of the seal or putting a needle valve is normally considered to regulate the flow required.
- Flow control system is usually considered to achieve reduced seal gas flows since the flow rate is more or less constant and does not vary with labyrinth clearance.
- A minimum seal gas velocity of 8 – 9 m/s is generally considered by most Original Equipment Manufacturer (OEM) for labyrinth seals while taking into consideration their normal wear and tear. It is to be noted that velocity across the labyrinth seal decreases over time as the clearances increases.
- Flow Control recommended over Differential Pressure Control to minimize seal gas consumption.

PRIMARY GAS SEAL VENTING AND HEALTH MONITORING

Primary Gas Seal Venting

- As shown in Figure 10 [API 614, 2014], out of the total Seal gas injected between the process side labyrinth seal and Primary gas seal (inboard seal), very small amount of sealing gas flows out of the Primary vent through Primary gas seal, and
- Out of the total Secondary Seal Buffer gas (inert gas N₂) injected between the intermediate labyrinth seal and Secondary seal (outboard seal) as shown in Figure 12, a further small amount of Buffer gas also passes through the intermediate labyrinth out of the Primary vent.
- Primary Vent is normally connected to the flare system.
- In order to prevent any potential reverse flow from the flare system into the Primary vent areas, installation of check valve is a must in the primary vent line.
- Typical leakage rate = 5 – 15 scfm (seal Gas + N₂).
- A low point drain valve need to be installed in the Primary vent line for removal of any accumulated liquids in the Primary vent areas.

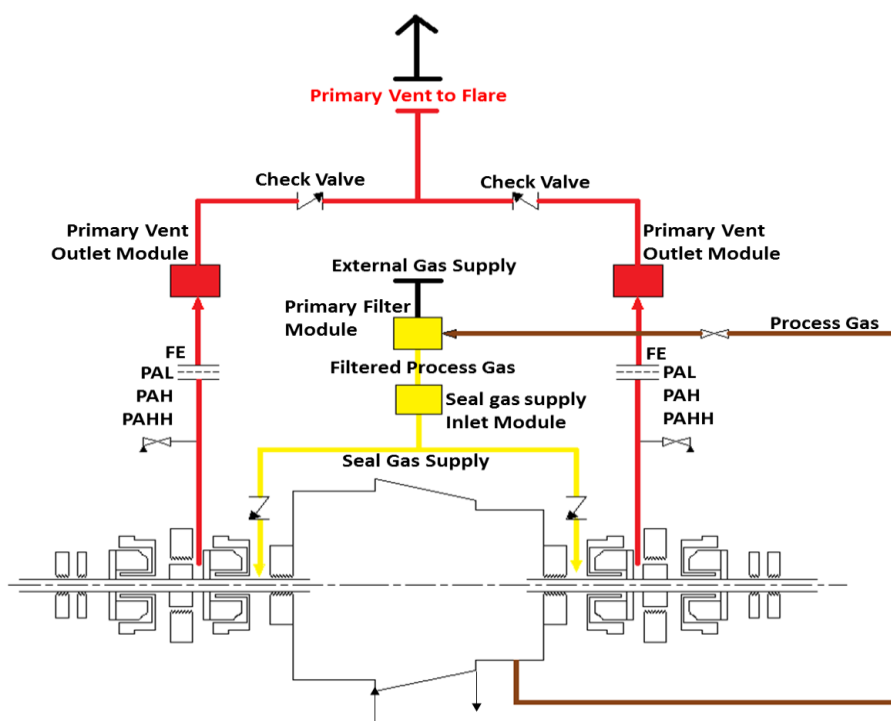


Figure 10 Primary Gas Seal Venting



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Primary Seal Venting – Safety Issues

- Design of Primary vent system must take into consideration the total failure of Primary Seal while the Secondary seal need to act as a back-up in case of Primary Seal failure.
- A controlled shutdown and depressurization of the compressor need to occur upon failure of the Primary seal and/or upon increasing pressure or flow above the acceptable leakage limits in the primary vent.
- Installation of a rupture disk as shown in Figure 11 [John S Stahley, 2002 – Turbomachinery Symposium] in parallel to the primary vent flow orifice is recommended in the primary vent line to reduce the back pressure in the piping upstream of the flow restriction orifice in the event of catastrophic failure of the Primary Seal.
- The rupture disc shall be fitted with an electronic detector for failure detection of the disc so as to replace it before re-starting the compressor unit. A non-permissive to start interlock of the compressor need to be provided using the electronic detector indicating a failed rupture disc.

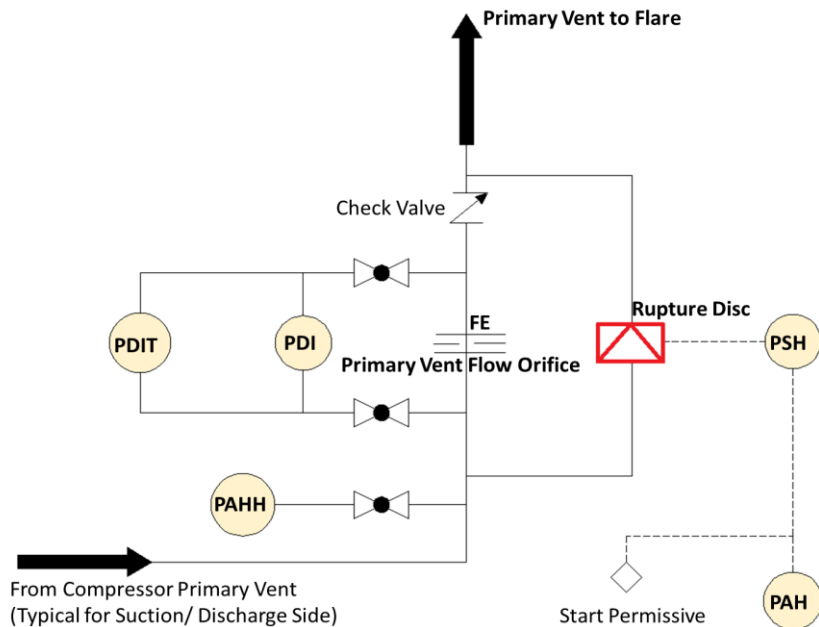


Figure 11 Primary Gas Seal Venting-Safety Issues

Secondary Gas Seal Venting

- As shown in Figure 12 [API 614, 2014], Secondary vent is normally vented to high point atmospheric safe vent without any restriction.
- Typical leakage rate = 0.1 scfm (mostly N₂).
- The Secondary vent piping should also be equipped with low point drain valves to allow inspection and removal of any lube oil from the Secondary vent areas.

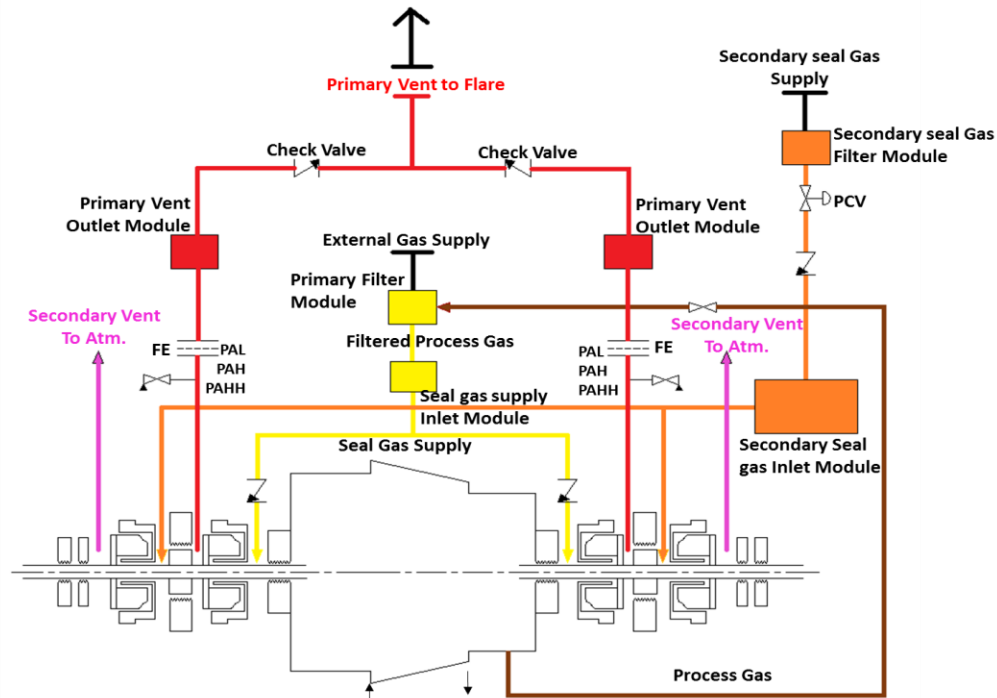


Figure 12 Secondary Gas Seal Venting

Primary/Secondary Gas Seal Health Monitoring

- Monitoring gas leakage through Primary vent.
- Installation of restriction orifice (RO) in the Primary vent line to measure flow or pressure as shown in Figure 12 [API 614, 2014].
- Deterioration in Primary seal health can be determined through measurement of an increasing flow or pressure trend through the Primary vent.
- Deterioration in Secondary seal health can be assessed by measuring the DP between secondary vent and primary vent.
- Ensure that both the Primary seal (Inboard seal) as well as Secondary seal (Outboard seal) are adequately instrumented and alarmed.
- A trip to be initiated upon increasing pressure or flow above a pre-determined limit in the Primary vent.
- High Pressure in Primary vent (PV) = Inboard (IB) seal failure.
- Low Pressure in Primary vent (PV) = Outboard (OB) seal failure.
- Health of Secondary seal is greatly affected by contamination from bearing lube oil.

SEPARATION GAS SUPPLY AND CONTROL REQUIREMENTS

Ensure adequate and clean separation gas supply to the barrier seals

- Ensure adequate supply of separation gas to prevent lube oil migration into the dry gas seal as shown in Figure 13 [API 614, 2014].
- Separation gas supply quality recommended at connection point:
 - Solid Particle size ~ 5 um
 - 99.97 % liquid free
- Duplex filter assemblies with change-over valve to allow filter element replacement during operation.



- Filtration to at least 5 um (absolute) or better.
- Use of N₂ as separation gas medium is highly recommended.
- Use of instrument air as separation gas medium requires caution. Flammability risk analysis need to be done.
- Barrier seal leakage changes with time.
- A suitable back up source or instrumentation to be considered for Monitoring.

Separation Gas Supply and control to the Barrier Seals

- Ensure separation gas supply pressure to barrier seals is adequately controlled using a Differential pressure control system
- Should be controlled to:
 - 3 psi to 5 psi for Labyrinth barrier seals
 - 5 psi to 10 psi for carbon rings barrier seals
- Differential pressure gauge to be installed between the separation gas supply and Secondary vent.
- Interlock with bearing oil.
- Low pressure in PV = OB seal failure.
- Worn out barrier or separation seals can be detected by presence of increasing amount of lube oil in the secondary vent drain over time during periodic inspections.

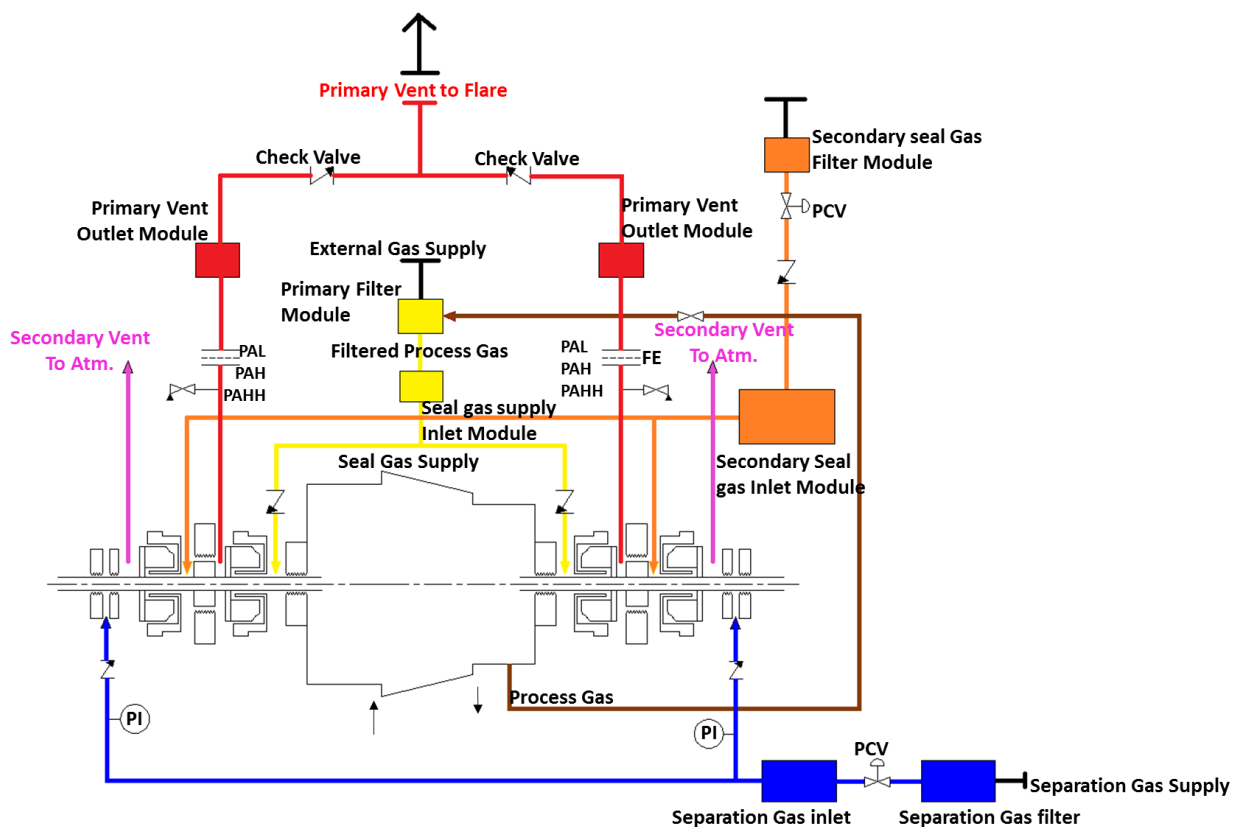


Figure 13 Separation Gas Seal supply and Health Monitoring



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RECOMMENDED ALARM AND SHUTDOWN CONDITIONS

Recommended Gas seal system alarm, shutdown and permissive-start conditions are given in Table 1 below:

Table 1 – Recommended Alarm and Shutdown Conditions

Parameter	Alarm Condition	Shutdown Condition	Permission to Start
Seal Gas Filter Differential Pressure	High	-	-
Seal Gas Supply Flow	Low	Low Low	-
Primary Vent Pressure or Flow	High	High High	-
Secondary Buffer Gas Supply Flow	Low	-	-
Secondary Vent Pressure or Flow	High	-	-
Separation/Buffer Gas Filter Differential Pressure	High	-	-
Separation Gas Supply Differential Pressure	Low	Low (Delayed)	Required

CONCLUSIONS

- Dry Gas Seals are being applied to a growing number of new centrifugal compressors and to older designs as retrofits. This is due to their improved reliability, operating availability and lower life cycle maintenance cost benefits.
- For an effective, reliable, safe and economical Dry Gas Seal system, design considerations are important. Equally important is proper communication during the design phase between the compressor OEM as well as the user.
- Working closely with gas seal manufacturer and compressor OEM during the design phase and performing HAZOP studies will enable selection of the best design for the intended application.
- Operations and maintenance practices for the compressor as well as the Dry Gas Seal system do affect seal reliability and uptime.
- Design, operational and maintenance considerations are also needed to mitigate seal gas contamination issues in order to improve Dry Gas Seals reliability and availability.
- Dry Gas Seal health monitoring is of paramount importance especially the tracking and trending of Primary seal vent pressure/flow along with pressure differential between the seal gas supply and seal gas reference pressures.

NOMENCLATURE

API	=	American Petroleum Institute
DGS	=	Dry Gas Seal
DP	=	Differential Pressure
FIT	=	Flow Indicating Transmitter
HAZOP	=	Hazard and Operability Study
IB	=	In-board
JT	=	Joule-Thomson
N ₂	=	Nitrogen
OB	=	Out-board
OEM	=	Original Equipment Manufacturer
PDT	=	Differential Pressure Transmitter
PT	=	Pressure Transmitter
PV	=	Primary Vent
PCV	=	Pressure Control Valve



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RO = Restriction Orifice
SCFM = Standard Cubic Feet Per Minute
SV = Secondary Vent

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